# Cherenkov Radiation from $e^+e^-$ Pairs and Its Effect on $\nu_e$ Induced Showers

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Cherenkov radiation from relativistic particles has been known for over 70 years. However, to date, almost all studies have concentrated on the radiation from individual particles. Several efforts have considered the Cherenkov radiation from electric and magnetic dipoles, but only in the limit of vanishing separations $d$. We consider another case, the reduction of radiation from slightly-separated oppositely-charged co-moving pairs. This includes $e^+e^-$ pairs produced by photon conversion. [1]

When high-energy photons convert to $e^+e^-$ pairs, the pair opening angle is small and the $e^+$ and $e^-$ separate slowly. Cherenkov radiation from closely spaced $e^+e^-$ pairs can be derived by extending the derivation for point charges [2], with the replacement of a point charge by an oppositely charged, separated pair.

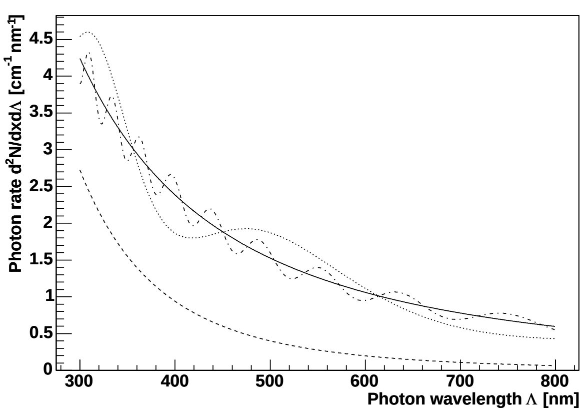


FIG. 1. The spectrum of Cherenkov radiation at $\beta = 1$, $\sqrt{\varepsilon(\omega)} = n = 1.3$. Solid line is for $e^+e^-$ with the particles considered independently, and the dashed lines are for pairs treated coherently, with separations 100 nm, 1 $\mu$m and 5 $\mu$m.

Fig. 1 shows both models: the pair treated as independent particles (solid) and coherently (dashed). As the photon wavelength $\Lambda$ approaches $d$, the pair spectrum converges to the point-charge spectrum in an oscillatory fashion.

Many experiments study Cherenkov radiation from large electromagnetic showers. The radiation from a shower may be less than would be expected if every particle were treated as independent. We use a simple simulation to consider 300 to 800 nm radiation from electromagnetic showers, generating 1000 $\gamma$ conversions to $e^+e^-$ pairs with total energies from $10^8$ to $10^{20}$ eV. Pairs were produced with the energy partitioned between the $e^+$ and $e^-$ following the Bethe-Heitler differential cross section $d\sigma \approx E_\pm(1-E_\pm)$, where $E_\pm$ is the electron (or positron energy) The $e^-$ and $e^+$ are tracked through a water medium (with $n = \sqrt{\varepsilon} = 1.3$) in steps. At each simulation step, the particles multiple-scatter, following a Gaussian approximation. The particles radiate bremsstrahlung photons, using a simplified model where photon emission follows a Poisson distribution.

To quantify the effect of Cherenkov radiation from $\nu_e$ interactions, we use a toy model of an electromagnetic shower. The shower evolves through generations, with each generation having twice as many particles as the preceding generation, with half the energy. In these showers, most of the particles are produced in the last generations.

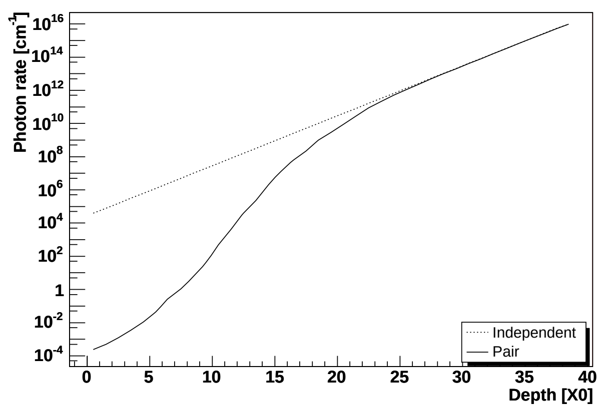


FIG. 2. Cherenkov radiation from a $10^{20}$ eV shower in water, using the Heitler toy model, versus shower depth (smoothed). The two curves compare the radiation for $e^+e^-$ calculated as independent particles and as coherent pairs.

Fig. 2 shows the Cherenkov radiation expected from a model $10^{20}$ eV shower with coherent Cherenkov radiation (solid line) and in a model where all particles radiate independently (dotted line). It is clear from Fig. 2 that coherence has a significant effect for the first 22 generations. Since the front of the shower contains relatively few particles, it will not affect the measured energy. However, by suppressing radiation from the front of the shower, it could affect the measurement of the shower development and the reconstruction of the shower position.

[1] S. K. Mandal, S. R. Klein, J. D. Jackson, arXiv:physics/0506078.
[2] J. D. Jackson, *Classical Electrodynamics*, 3rd edition (John Wiley & Sons, New York, 1998).